TREE GROWTH RESPONSES TO CHANGES IN THE PHYSICAL AND CHEMICAL CLIMATE AND METHODS TO ASSESS ECONOMIC CONSEQUENCES

J. Maybank and E. Wheaton
Saskatchewan Research Council, 15 Innovation Boulevard, Saskatoon, Saskatchewan, Canada S7N 2X8

G. C. Van Kooten
Department of Agricultural Economics, University of Saskatchewan, Saskatoon, Saskatchewan, Canada S7N 0W0

ABSTRACT:

While various changes in climate are recognized as occurring, the one of primary concern today is based on the well-documented rise in atmospheric carbon dioxide concentrations. The direct beneficial aspect, to tree growth, of this rise must be incorporated into an climate effect predictions. These latter evolve from the known capability of CO_2 to absorb infrared wavelengths, thereby altering the earth's radiation budget.

The search for and assessment of appropriate methodologies for climatic change impact assessment for Canadian boreal forests and the forest industry is discussed. Climatic change scenarios are classified and some of their advantages and disadvantages are assessed. The implications of relevant methods and findings are provided. A framework to examine the available models is needed. A system design is applied to demonstrate and evaluate the linkages and feedbacks among components. In order to determine the total effect an economic component is included.

Thus the methodological issues of measuring the economic benefits of climatic change on boreal forests are also discussed. The net economic benefits of a change in climate that affects the growth of boreal forests are equal to the value of the change in timber volume plus the change in rent accruing to firms as a result of a change in economic activity. The methods for measuring this net benefit vary from one study to another, and improved methods must be developed.

KEYWORDS: carbon dioxide, climate, climatic change, forest climatology, forest economics, tree growth.

1 INTRODUCTION

The forest area under consideration for the purposes of this study is the boreal forest of the Prairie Provinces and Northwest Territories. The importance of the boreal forest should be emphasized. It is of considerable value to our economy and society to several aspects of the environment.

The significance of forestry to the Canadian economy is well known; in 1984, forestry products accounted for 14.0% of all Canadian exports. The contribution of the prairie provinces to forest production can be determined by examining statistics for the study region relative to that for Canada as a whole (Table 1).[1] The study region accounts for only 5.1% of all employment, value-added and value of shipments in forestry; and it accounts for only 4.5% of total forest product exports. Nonetheless, the region constitutes 36.7% of the total available productive forest land area in Canada and 24.0% of the unproductive forest land area. In addition, the study region's forest accounts for over 13% of the gross merchantable timber volume available in Canada. Thus, although these forests do not contain as much commercial timber by volume as some of the other areas in Canada, particularly the coastal region of British Columbia, the study area forests are also under-exploited at the present time. The main reason they are under-exploited has to do with accessibility and distance to market, although these problems are decreasing as remote regions are opened up for other uses and cheaper modes of transport become available.

The forest also provides irreplaceable habitats for wildlife, other plants and fish. Furthermore, the forest acts to regulate water flows and prevent soil erosion. Thus recreation and tourism based on these aspects of the environment are made possible.

What is the connection to climate? The boreal forest is greatly influenced by climate. Indeed, climate is one of the chief factors affecting the boreal forest. The structure and function of a forest ecosystem are more clearly dependent on climate than are those of many other ecosystems (Havas 1971). Tree ring data that are closely correlated with climate are often from marginal locations such as the northern tree line (LaMarche 1978). The climatic control of the distribution of the boreal zone, especially its northern limit, is well documented (Peterson et al. 1983). Climatic factors related to temperature exert more obvious controls over primary productivity in boreal forest ecosystems than do those related to precipitation (Peterson et al. 1983, Kauppi and Posch 1984). Because climate strongly affects this vital renewable resource, the forest, its influence on the forest should be carefully studied. Many aspects of forestry, including productivity and tree physiology, forest zonation, fire risk, and insects and

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[1]Although the study area stretches into the Northwest Territories and the forest area there is quite large, the economic importance of the forests in the Territories is insignificant. The statistics for the Territories alone are not available as they have been combined with British Columbia's statistics.

Table 1: Forestry Statistical Summary for the Study Region Relative to Canada as a Whole

	CANADA	ALBERTA	SASK	MANITOBA	PRAIRIES
FORESTED AREA (1981)			(1 000 km^2)		
Productive	2,642	234	111	624	969
Unproductive	1,723	115	89	209	413
INVENTORY OF GROSS MERCHANTABLE WOOD VOLUME (1981)			(1 000 000 m^3)		
Softwoods	15,570	781	293	439	1,513
Hardwoods	4,074	657	191	196	1,044
Total	19,644	1,438	484	635	2,557
EMPLOYMENT (1983)					
Logging Industry	45,943	746	560	446	1,752
Wood Industries	101,965	5,418	X	2,010	7,428
Paper & Allied Industries	114,308	2,239	X	1,859	4,198
VALUE ADDED (1983)			($1 000 000)		
Logging Industry	2,158	33	33	14	80
Wood Industries	3,993	235	X	59	294
Paper & Allied Industries	5,940	165	X	79	244
VALUE OF SHIPMENTS OF GOODS (1984)					
Logging Industry	5,364	96	72	56	227
Wood Industries	9,973	539	110	135	784
Paper & Allied Industries	17,472	452	X	218	670
EXPORTS (1984)	15,730	415	146	145	701

X indicates that the information is confidential under the Statistics Act.

Source: Canadian Forestry Service (1986).

diseases are inextricably linked to climate.

While various changes in climate are recognized as occurring, the one of particular concern currently is that based on the well-documented rise in atmospheric carbon dioxide (CO_2) concentrations. There is widespread concern regarding the possibility of climatic warming due to the increase of atmospheric CO_2 and the other "greenhouse-effect" gases. The Global Climatic Model (GCM) simulations of a climate with increased CO_2 levels clearly show increased temperatures, especially at the higher latitudes. A recent paper (Jones, Wigley and Wright 1986) has provided observational evidence of worldwide warming over the past 10 to 15 years. Singh and Powell (1985) examined the climatic variation and trends of the boreal forest area of the prairie provinces and Northwest Territories and found significant warming trends in the 1972 to 1981 period. Shewchuk (1984) has noted an apparent trend towards increasing temperatures in the past two decades, particularly in winter. Therefore, even the regional trends appear to be showing increasing temperatures for this study area.

It is then logical to ask: What are the implications of climatic warming for the boreal forest? The effects may be quite pronounced because of the combination of the forest's sensitivity to climate especially temperature, and the fact that the greatest temperature increases are expected for the high latitudes which is where the boreal forest is located.

Also, unlike the effects on other sectors such as transportation, recreation, energy, etc., the increase of atmospheric carbon dioxide has a double faceted effect on vegetation. In addition to the climatic impact, there is the physiological response of the plant. CO_2 is essential for plants, and within limits, increasing CO_2 increases plant growth and primary productivity (e.g. Dahlman 1985). Water use efficiency for some plants also increases with increasing CO_2 levels (e.g. Rogers et al. 1983). This latter effect is especially important in the southern boreal forest, for example, where moisture stress may be restrictive. With climatic warming moisture stress could also become more significant in the northern boreal forest.

Also different plant species respond differently to CO_2. What if competing plants are able to make better use of the effects of increasing CO_2, either directly or indirectly as a result of changes in the bioclimatic environment? Then some of the questions in the context of vegetation are: What are the direct effects on plants and ecosystems of an increase of CO^2_2? What are the effects of climatic warming in combination with these direct effects of an increase in CO_2? The questions may be straightforward but the search for the answers is very complex.

In order to start to address this question we need to find and adapt or perhaps derive the appropriate methodology. Also, the methodology should be interdisciplinary, consisting of a set of procedures, perhaps in the framework of a systems approach. This paper reports our effort in searching for and assessing methodologies. It also examines the implications of the relevant methods and findings in the literature.

2 LITERATURE REVIEW AND IMPLICATIONS FOR THE STUDY

2.1 Effects of Climatic Warming on the Boreal Forest

Although a few studies have examined the potential effects of the expected climatic warming on agricultural crops (e.g. Parry et al. 1987, Arthur et al. 1987), very few have focussed on the boreal forest. Kauppi and Posch (1984, 1985) are among the few exceptions. Kates (1986) has provided an overview of climate impact assessment and refers to some relevant work in forestry. Other literature that is relevant are the biomass studies including Williams (1985), Williams and Masterton (1983), Williams et al. (1987) and Emanuel et al. (1985). The bibliography compiled by Peterson et al. (1983) is useful as it includes the references dealing with the impact of climatic variation on biomass accumulation in the boreal forest zone. Results of examining the effect of past warming can help in the estimation of the effects of future warming.

Peterson et al. (1983) list many climatic factors and indicate their effect on net primary productivity of the boreal forest ecosystem. Several of the effects listed would potentially occur in a warmer climate. Many of the temperature factors that may occur with a warmer climate have caused an increase in net primary production in the past, but about a fifth of the total have caused a decrease in production. The situation is very complex and must be assessed by means of a comprehensive model or set of models before we can estimate the direction productivity will change given our current knowledge of the characteristics of the new climate.

Williams (1985), Williams et al. (1987) and Williams and Masterton (1983) have used an index of dry-matter productivity to assess the sensitivity of bioresources in Alberta and in Saskatchewan, Canada. The index reflects both moisture and temperature effects and thus is quite appropriate for an area such as the prairies where both effects can be pronounced. The results for the study area indicate that warming would increase potential productivity in northern Alberta and Saskatchewan, but increase it only slightly further south for the forest grassland transition zone because of the associated increased moisture stress. The estimated potential productivity increases for the boreal forest in Saskatchewan ranged from about 75% in the north to about 20% greater at the forest-grassland transition. These results were calculated using the 2 x CO_2 simulation results for temperature and precipitation from the Goddard Institute for Space Studies model (Hansen et al. 1984).

Kauppi and Posch (1987) examine some of the same warming scenarios and evaluate both the shift in the position of the boreal forest and its productivity using Finnish forestry data. The present northern and southern boreal forest boundaries were delimited according to the 600 and 1300 growing degree day isopleths. The match of the 600 growing degree day isopleth and the observed northern boundary is reasonable for land areas extending from Western Canada eastward to Western Siberia. A comparison of these isopleths with the forest boundaries for the study area also show a favourable match. Their preliminary results for a 2 x CO_2 climate show a substantial shift in the boreal forest zone (Kauppi

and Posch 1984). The northward shift is estimated to range from 500 to 1000 km, which would mean that the southern boundary of the boreal forest under a 2 x CO_2 climate would be where the northern timberline is today. These preliminary results have major ramifications for forestry and forest-based activities.

2.2 Direct Effects (Physiological) of CO_2 on Vegetative Growth

The direct beneficial effect of increasing CO_2 is now widely recognized for agricultural crops (Kimball 1983). Some skepticism does remain, however, as much of the research is based on work in growth chambers and greenhouses, and little work has involved the more numerous and less controllable range of outdoor variables. Recognition of the direct biological effect of CO_2 has, in turn, necessitated a re-analysis of inputs for plant growth models (Dahlman 1985, Reynolds and Acock 1985). Most of these models developed to date are based on a fixed CO_2 concentration, not on increasing amounts. Once the adjustment to incorporate a new variable, CO_2, has been accomplished, and the resultant model tested, the more difficult task of integrating them with the climate change scenarios must be addressed.

The situation with respect to CO_2 and the forest is at least as complex, with less evidence of the magnitude of a direct biological effect. Kimball (1983) has summarized results for a few tree species grown in enriched CO_2 environments. Again, as for agronomic species, trees seem to use water more efficiently at elevated CO_2 levels (Rogers, Thomas and Bingham 1983), and their photosynthetic rate is improved. However, the relatively short durations of all such experiments render the results less reliable than for wheat or corn, for example.

There are, however, already some modest indications of increased tree growth through the direct biological effect of CO_2 (LaMarche et al. 1984). These findings emphasize the importance of including the direct effects of CO_2 in conjunction with assessments of the impacts of climatic change due to increased amounts of CO_2.

2.3 Economic Consequences of Climatic Warming

The economic consequences of climatic warming, particularly as these pertain to agriculture, have been examined by a number of researchers (Arthur et al. 1987; Parry et al. 1987; Williams et al. 1987). However, there has been no attempt to develop an appropriate methodology for analyzing the economic benefits and costs of climatic change. Where economic impacts have been analyzed, the procedure has been to use linear programming (farm models) to determine the changes in agricultural output and then to estimate the economic impacts using input-output models (e.g., Parry et al. 1987; Williams et al. 1987). Unfortunately, this does not get at economic benefits; however, in most other studies, the emphasis is on the physical, as opposed to economic, impacts of climate change (e.g., Kauppi and Posch 1984). Where attempts are made to estimate the economic benefits, benefits are either left undefined or appear to be erroneously calculated, possibly because many of the economic studies were not conducted by experienced economists.

In this paper we will suggest an appropriate methodology for estimating the economic benefits (or costs) of climatic change as it affects the Canadian boreal forest. With this purpose in mind, we review some earlier Canadian studies of the economic benefits of climatic change and argue that previous economic measures may be misleading. We proceed by first examining the forest economy of the study region in relation to the national forest economy. Then we make a distinction between economic benefits and socio-economic impacts. Our discussion of economic consequences ends with an illustration of an appropriate method for evaluating the economic benefits of climate change on the Canadian boreal forest.

3 METHODOLOGY ASSESSMENT FOR CLIMATIC CHANGE IMPACT STUDIES

3.1 Developing Climatic Change/Variability Scenarios

Various types of climatic scenarios can be used to depict a warmer climate as may be expected with a doubling of atmospheric CO_2. A climatic change scenario has been defined as a description of the spatial patterns and seasonal behaviour of temperature, precipitation, and other important meteorological variables in an altered climatic state (Santer 1985). Climatic change scenarios of various types have been used. These can be classified as follows: 1) historical analogues, 2) synthetic, 3) GCM-derived and 4) hybrid climatic change scenarios.

Historical analogues are especially useful if there is a sufficient length of record for the selection of extremely anomalous periods. Or they may be constructed from paleoclimatic data based on proxy information such as that from tree rings, ice cores, etc.

A set of these scenarios can be quite flexible as they may use single anomalous years, an extreme decade or an extreme period of years. They also have the advantage of representing conditions that actually occurred in the past. The past has often been viewed as being the key to the present and the future. Also, because they can occur in the next season or year, these scenarios have greater implications for the near future than do the GCM scenarios of enhanced CO_2, for example.

However, scenarios based on past records of climate are not very suitable in the context of changes in atmospheric chemistry. Because such elevated levels of CO_2 as double the pre-industrial amount have not occurred in the historical past, the warmer historical periods must have been caused by other mechanisms. Therefore, they may not even come close to duplicating the characteristics of a warmer climate caused by the "greenhouse-effect" gases. Also the projected warming is greater and more uniform globally than any period in the historical record.

Synthetic climatic change scenarios can be created by combining and/or adjusting historical data. A synthetic series can be created by selecting single anomalous years, seasons, etc. and placing them consecutively in a sequence. Or this type of scenario can be constructed by adjusting historical data by increasing temperature arbitrarily by a

certain range of degrees and increasing rainfall by certain percentages, for example. This may be one way of forcing the historical data to conform to what may be an enhanced CO_2 level. But it may result in the analysis of an excessive number of combinations of temperature and precipitation, some of which may have a low probability of joint occurrence and may not have CO_2 as the driving mechanism for the change.

Thus some impact modelers have turned to the GCM simulations to provide sets of perturbed climatic data as inputs to impact models. The GCM results provide a powerful technique to explore the nature of climate in a warmer world because they overcome many of the problems inherent in the use of the previously mentioned types. Their usage also entails advantages not mentioned above: 1)data are provided on a uniform grid point basis so the network uniformity is optimum 2) data are simulated which may not exist at some stations (e.g. some stations do not have precipitation records).

There are, however, several problems in using GCM results in estimating climatic impacts. One of these is that the 1 x CO_2 results often do not conform well to the observed climate (Williams et al. 1987, Wilson and Mitchell 1987). It is usually inappropriate to use GCM results for 1 x CO_2 and 2 x CO_2 **directly** as inputs to impact models. This problem may be overcome by using the difference between (for temperature) and ratio of (for precipitation) the 2 x CO_2 and the 1 x CO_2 GCM results as adjustments to historical data. The historical data and the adjusted data are then used to simulate the 1 x CO_2 and the 2 x CO_2 climates. Hopefully the comparison between the two simulations better indicates what the perturbed climate may be like. GCM modelers are also striving to improve their ability to simulate climatic reality given the complexity of the atmospheric-oceanic-geographic (e.g. vegetation, land form, hydrology) system to be modelled and of the computer requirements of such work.

Another problem with using GCM results is that data that have been calculated for climatic parameters such as wind, atmospheric circulation, and evaporation, may not be available to those doing the impact studies. As communication between the GCM and impact modelers is increasing, this problem is decreasing.

Inadequate spatial resolution is also a limitation of GCM results. Data are not available for the smaller regional areas but only for widely spaced gridpoints. Spatial interpolation can be used in calculating the differences and/or ratios for applying the historical data for small areas (Williams et al. 1987), but this does not overcome the basic problem of lack of sufficient spatial resolution of GCM results.

Inadequate temporal resolution is another shortcoming of GCM results. Data are available only as monthly or seasonal means. A knowledge of extreme events and their frequencies rather than just means is also useful to impact modelers and is economically significant; examples are frost and strong winds (Wilson and Mitchell 1987).

Little or no information exists regarding the statistical distri-

bution of the parameters (distribution type, variation, etc.). Usage of the GCM results, in absence of this information, also entails invoking several assumptions, such as that the changed climate will have the same variability as the past climate.

More information is needed about the climatic response to an increase in CO_2 over time (Santer 1985). This would provide more than just a snapshot in time at the 2x CO_2 level.

These are just some of the problems that are especially important in impact studies. Many of them can be overcome, however, so there is certainly a great deal of impact assessment that can be done in the meantime. In fact, in many cases, the impact models are at as early a developmental stage as the GCMs, or they do not even exist in many instances.

The use of hybrid climatic change scenarios may sometimes be more realistic than employing those based on the GCM results alone. Williams et al. (1987) have used this type in agricultural impact assessment. These hybrid scenarios are an effective combination of two or more types, such as the GCM derived scenarios for some parameters and historical and or synthetic data for others.

Hybrid climatic change scenarios are especially useful when some necessary parameters for an impact model are not available from the GCM results or when a parameter has been modelled with somewhat less confidence than desired. For example, Williams et al. (1987) used a combination of temperature adjustments based on the Goddard Institute for Space Studies GCM experiments (Hansen et al. 1984) and historical precipitation data. Hybrid scenarios can help overcome the spatial, temporal, geographic and snapshot problems encountered when using the GCM results only. So while the climatic modelers proceed to improve the GCMs, the impact modelers also have a wide variety of techniques to use in making the much needed improvements in their own modelling.

3.2 The Concept of Economic Benefits as Opposed to Socio-economic Impacts

In order to study the economic implications of climatic change, it is necessary to employ techniques developed in applied welfare economics, which forms the theoretical foundation of benefit-cost (B-C) analysis (Boadway 1974; Boadway and Bruce 1984; Diewert 1983; Just et al. 1982). In this literature, economic benefits refer to surplus areas either below the demand function and above price or above the supply function and below price. These concepts are known as consumer surplus and producer surplus (or rent), respectively.[2] In Figure 1, the equilibrium price is P^e. The consumer surplus at this price is given by area (P^ebc), while the producer surplus is measured by area (abP^e).

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[2]Consumer surplus is actually an approximation to one of the two true measures of the welfare of a consumer, namely, compensating variation or equivalent variation (Boadway and Bruce 1984; Just et al. 1982).

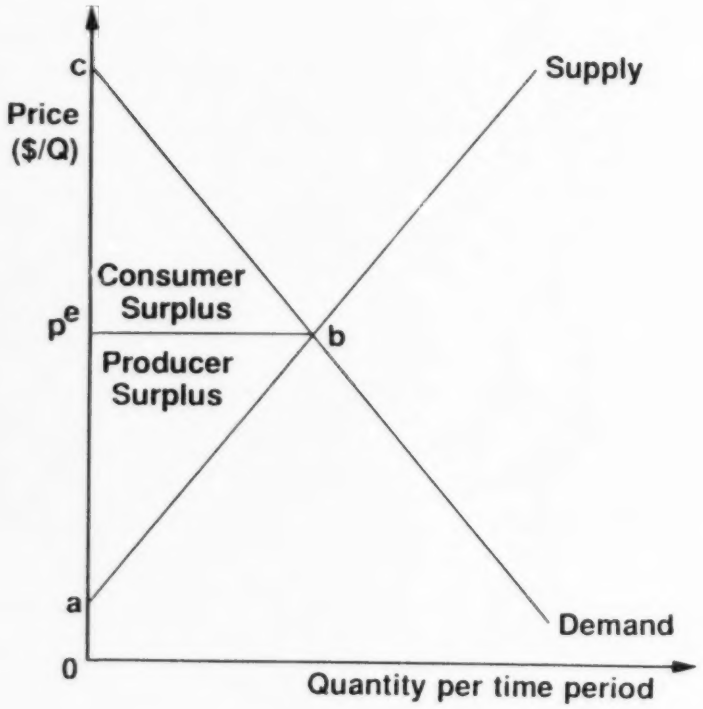

Figure 1. Concepts of Consumer and Producer Surplus

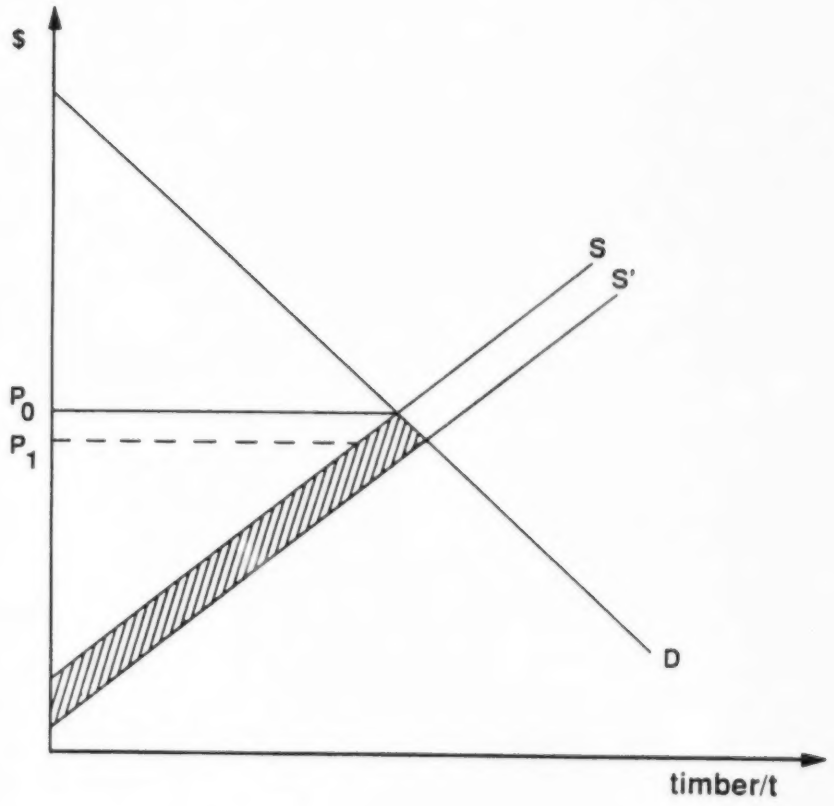

Figure 2. Welfare Change per Unit of Time

It is also important to distinguish between indirect economic "benefits" and indirect economic "effects". In the B-C literature, the concept of indirect benefits is well-established (Harberger 1971); but, in practice, there is much confusion between indirect effects and indirect benefits. Indirect effects or secondary effects are often erroneously referred to as secondary economic benefits by regional analysts and planners. They are also referred to as socio-economic impacts and these cannot be compared with economic benefits, although calculation of economic impacts may be useful to the authority in making decisions regarding the extent of income transfers between regions. Since indirect effects or impacts deal with pecuniary external economies or income distributional issues, they are not eligible as benefits in evaluating projects via benefit-cost analysis, or in determining the net economic benefits of changes in climate.

Indirect benefits, on the other hand, are appropriate to include in the estimation of the economic benefits of a change in climate, but only in certain circumstances. Indirect benefits are measured when welfare impacts are to be calculated in a general rather than a partial equilibrium framework. What distinguishes the general from the partial framework is that the former takes into account welfare impacts in markets that are only indirectly affected by climate change. For example, climate change may increase the supply of timber products to firms producing paper products and/or it may increase the demand for logging equipment such as trucks. Indirect net economic benefits may be measured in these markets. It is clear from the applied welfare economics literature, however, that welfare impacts in the affected forward and backward markets, or horizontal markets, are to be measured only when there are economic distortions (e.g., monopoly) in these impacted markets (Harberger 1972, p.48; Just et al. 1982, p.459).[3]

The net economic benefits of a change in climate which affects the growth of forests are equal to the value of the change in timber volume, plus the increase or decrease in welfare measured in related, but distorted, forward- and backward-linked and horizontal markets as a result of an increase or decrease in economic activity in the forest sector. The latter welfare effects are the indirect economic benefits of the climatic impact. In addition, there may be an increase or decrease in employment and economic activity caused by climate changes which affect timber availability. These are the socio-economic impacts or indirect effects of the climate change.

The current method for identifying and measuring indirect effects is via input-output (I-O) models (Arthur et al. 1986; Parry et al. 1987; Williams et al. 1987), but these effects are not to be confused with benefits. In many economic studies, indirect effects obtained from I-O models are often incorrectly included as a part of economic benefits.

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[3]Other examples of economic distortions include pollution, the use of forests for recreational purposes and the use of forests as scenic amenities. The reason the latter two create distortions is that they are not adequately priced in the market, if at all (Brown and Daniel 1986).

This is inappropriate as it requires the mixing of two tools which are philosophically and analytically designed to address different issues; these tools are applied welfare analysis--the study of economic efficiency or measurement of benefits and costs--and input-output analysis.

With I-O analysis, indirect effects (or secondary impacts or regional "benefits") are calculated by increasing the appropriate category of final demand in the regional I-O model, with households exogenous. After reconstruction, this gives the increase in value-added occasioned by the type of expenditure in question. Only new processing industries are not treated this way since their development would alter the structure of the economy and, therefore, the I-O models. The value-added is then taken as a net indirect benefit in the B-C analysis. However, value-added is not a measure of benefit; it is merely the upper limit on the opportunity cost of the resources employed in the various activities which generate the value-added. Value-added constitutes only an income transfer or indirect effect, and not an economic benefit.

There is a major problem associated with calculating net indirect effects. Simulations using the input-output model produce estimates of impacts on the economy in question. The increase in value-added is one component of these impacts. However, impacts cannot be taken as net benefits. Specifically, value-added typically fails to take into account the opportunity cost of the resources used to generate this value-added--the I-O analysis only generates "benefits", but provides no information about costs--and this leads to a substantial overstatement of benefits.

If climate-induced increases in forest output occur, but the economy is at full employment, the increase in employment generated in some sectors of the economy (other than forestry and determined from the I-O model) constitutes a loss in other sectors. That is, despite the I-O results, there is no new employment generated, only a transfer from one sector to another. If there is persistent unemployment of resources, particularly labour as may be the case in natural resource dependent regions, then the induced employment (and indirect effects or impacts) could be included as a socio-economic plus due to the climate change. However, it needs to be determined if unemployment is indeed persistent and, if it is, whether the cause is structural (e.g., poorly trained labour force) or not. If unemployment is related to structural causes, then an increase in forestry output, for example, may do nothing to alleviate regional unemployment. If the regional labour force is unable to supply the skills required, labour will simply be attracted from other regions (an interregional transfer) or other countries. Indirect effects are obviously pecuniary if this is the case. Even if unemployment is not structural, it is not clear that forestry projects resulting from the increase in timber availability can be used to alleviate unemployment. The time required between authorization of projects to take advantage of the increased timber availability and construction of these projects may simply be too long (see Burns and Grebler 1984).

To summarize, input-output models are inappropriate for estimating

economic benefits and this approach is incompatible with applied welfare economics (benefit-cost analysis), and the latter is the correct methodology to use in evaluating the net benefits of changes in climate on the boreal forest. Even the social accounting model, which is an improvement over the I-O methodology but is similar to it, "does not capture the behaviour of economic agents interacting across markets in response to shifts in price signals... The model is demand driven and completely ignores issues of resource allocation, productivity, and factor utilization" (Adelman and Robinson 1986 p.1206). Rather, it is necessary to develop computable general equilibrium (CGE) models if one wishes to correctly estimate secondary or indirect effects. However, such models rely heavily on economic theory, and hence may be outside the purview of many B-C practitioners (e.g., planners, engineers), and they are expensive and difficult to construct.

3.3 An Appropriate Measure of Welfare and Methodology

In this section, we employ a partial equilibrium analysis to study the economics of climate change on the Canadian boreal forest. Thus, we assume that there are no distortions in other, affected markets--that is, we assume perfect competition with no externalities.[4]

In applied welfare economics and, therefore, in analyzing the economic benefits of climatic change for the boreal forest, it is important to determine the appropriate measure of benefits and costs--the correct welfare measure. This welfare measure subsequently becomes the objective function in an optimal control model. Lyon and Sedjo (1983) employ the sum of the welfares of consumers and producers as their measure of net benefit; these are the concepts of consumer and producer surplus, respectively, and they are illustrated in Figure 1. The impact of a change in climate can be illustrated in Figure 2 by an outward shift of the supply curve. If the climatic change causes an increase in the supply of commercial timber, then the shaded area between S and S' (the new supply curve) is a measure of the welfare gain or net benefit from climate change per period of time (Lovell and Smith 1985).

In the framework of Figure 2, the objective of the social decision maker is to maximize the present value of future producer plus consumer surpluses; that is, the objective is to maximize the discounted sum of surpluses. The measure of surplus for each time period can be written mathematically as:

$$s_t = \int_0^{V_t} [D_t(q) - S_t(q,M,C,\gamma)]\, dq, \qquad (1)$$

where s_t is the consumer plus producer surplus in year t;

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[4]Simply put, externality refers to pollution (e.g., acid rain), scenic amenities, non-market uses of forest lands (e.g., hunting) and so on. Clearly, the assumption of perfect competition holds only as an approximation.

V_t is the volume of commercial timber marketed under perfectly competitive conditions in year t;

$D_t(\ )$ is the demand function for timber in year t; and

$S_t(\ )$ is the supply function for timber in year t.

The supply of timber is a function of the volume of timber available, previous management decisions regarding regeneration (M), climate (C) and other parameters (γ) such as the costs of harvesting. Notice that the measure of surplus in (1) is not the same as private surplus, which would be equal to gross revenues minus costs; that is,

$$\text{private surplus in year t} = P_t V_t - \int_0^{V_t} S(q,.)dq$$

$$= \text{producer surplus,}$$

where P_t is the per unit price of commercial timber at time t.

In order to determine the benefit of a change in climatic conditions, the discounted surplus under the original climatic conditions needs to be subtracted from the discounted surplus under the new climate conditions. That is, the economic problem is to maximize the discounted net value of the objective given by (1) over time, subject to a number of dynamic constraints, including a forest growth constraint. One then compares the net present value of benefits under the optimal decision path for the original situation with the net discounted benefits under the optimal path for the alternative climate conditions. This requires an optimal control model (see Bowes and Krutilla 1985; Reed 1986).[5]

The situation depicted in Figure 2 and the measure of producer plus consumer surpluses (area abc) is valid only in a closed economy. As Canada exports in excess of 50% of its timber and timber products, the model in Figure 2 is not valid, nor is the welfare measure represented there. Rather, an international trade model is required. In Figure 3, it is assumed that Canada is a timber surplus region, while the United States is a timber deficit region. As in similar models, transportation costs are ignored, not because they are unimportant but because their inclusion does not change the basic analysis. Under free trade and before the impact of the climatic change, Canada exports an amount Oq_1 of timber to the U.S. The domestic price in Canada is higher under free

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[5]While Arthur et al. 1986 employ regression analysis and linear programming (LP) to estimate changes in agricultural output due to climatic shifts, LP is a static optimizing technique and is not really appropriate for analyzing dynamic problems such as those encountered in forestry. It should be noted that dynamic problems can, in some cases, be solved using LP. However, the major technique in these cases is still a dynamic one, not a static one such as LP.

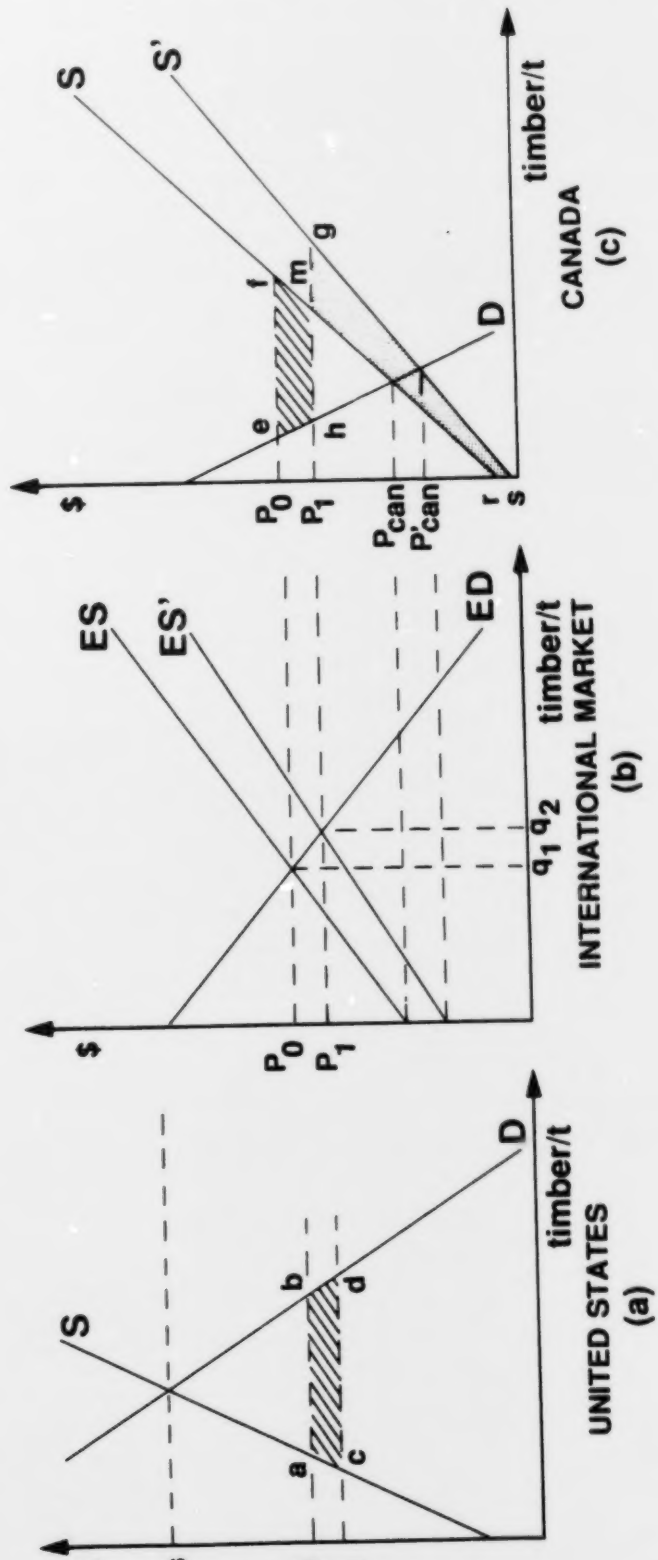

Figure 3. Benefits of Climatic Change in an Open Economy

trade than it would be in the absence of trade ($P_{CAN} < P^0$), while the opposite is true in the U.S.

The shift in Canada's supply of timber from S to S', due to a change in climate, causes the excess supply curve (panel (b)) to shift from ES to ES'. The free trade price drops from P_0 to P_1 and the quantity of timber traded increases to $0q_2$. In Figure 3(a), we find that there is a loss to U.S. producers equal to area (P_0acP_1), but U.S. consumers gain area (P_0bdP_1). The net gain to the U.S. from a climate change which affects only the Canadian boreal forest and not U.S. forests is given by area (abcd) in Figure 3(a). Canadian consumers also experience a gain in welfare which is measured by area (P_0ehP_1) in panel (c). Before the change in climate, Canadian timber producers earned a surplus given by area (rP_0f) in Figure 3(c); after the climate change the producer surplus is measured by area (sP_1g). The change in the welfare of Canadian producers is, therefore, area ($srmg - P_1P_0fm$) in Figure 3(c). The net gain to Canada is given by area (srmg - efmh) or the fully shaded area minus the partially shaded area. Without knowing the elasticities of supply and demand and the extent of the supply shift, it is not clear whether Canada experiences a net gain or loss on account of a climate change. It is clear, however, that the U.S. will be a net gainer of a change in climate whose only effect is to increase the productivity of Canada's boreal forests.

It is also necessary to take into account trade distortion. The U.S. government threatened to levy a countervail duty on Canadian exports of timber products (i.e., softwood lumber) as these were, apparently, being subsidized.[6] In response, the Canadian government offered to impose voluntary restraints, and these were accepted by U.S. authorities. Bowes and Krutilla (1987) estimate that the welfare loss to Canada would be $78.6 million if the U.S. imposes a 10 percent ad valorem tax; about $5 million would be lost in the current study region.[7] However, under voluntary restraints which reduce U.S. imports from Canada by the same amount, Canada would gain $99.2 million, and the gain to the study region would be $6.2 million. Since the actual restraints imposed by Canada exceeded the estimates by Boyd and Krutilla (1987), the gain to Canada was even larger.

Imposition of a countervail duty by the U.S. or voluntary restraint by Canada lowers the Canadian domestic price, but increases the price in the U.S. (Figure 4). The amount traded is given by distance ab in panel (a), which is equal to distance sr in panel (b). In Figure 4, the free trade price is P_0, while the price under trade distortion is P_1. Imposition of a countervail duty by the U.S. results in a welfare gain by U.S. producers, but an even greater loss to U.S. consumers of timber products. The gain to U.S. producers is area (P_1afP_0) in Figure 5.3(a), while the welfare loss to consumers is P_1bcP_0. Since the government

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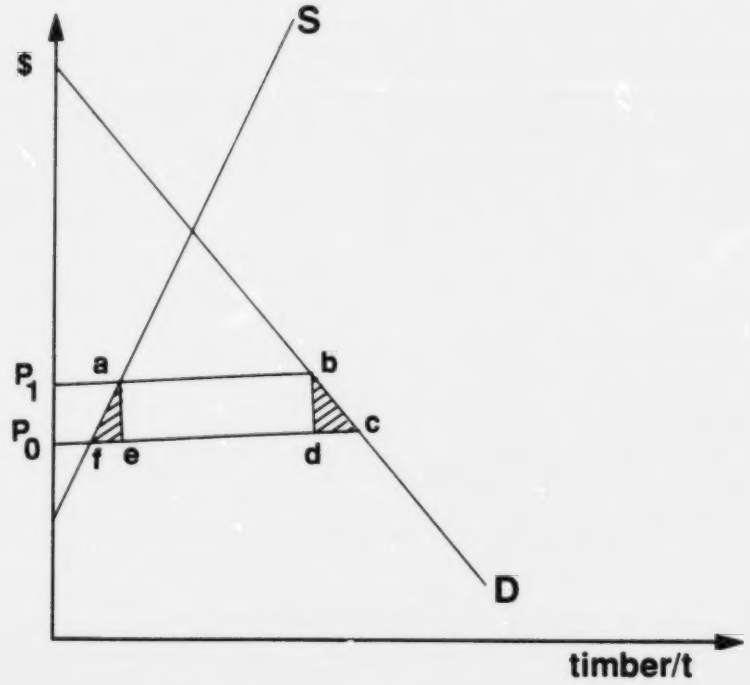
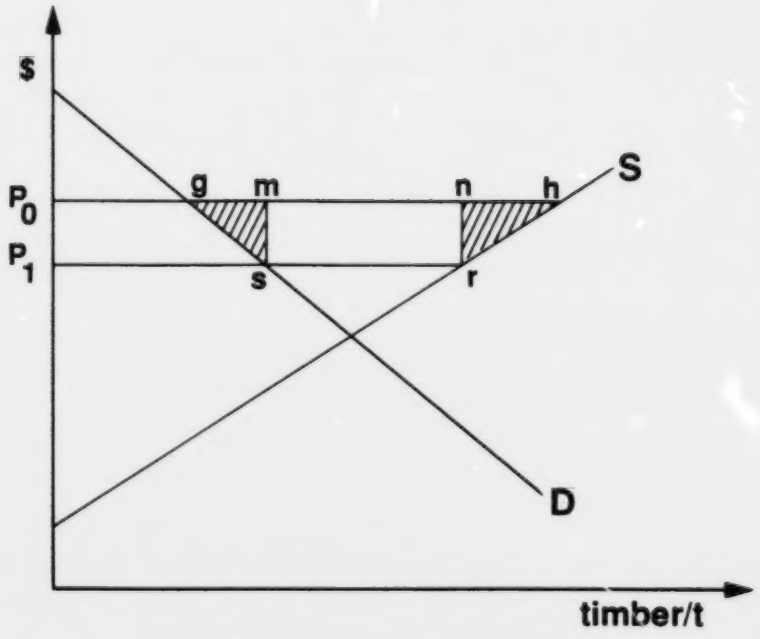
[6]It is extremely difficult to determine the extent of subsidy in these cases. For a discussion in a natural resource context see Schmitz et al..

[7]This assumes an elasticity of supply of 0.89.



UNITED STATES
(a)



CANADA
(b)

Figure 4. Welfare Gains and Losses with Trade Distortion

collects area (abde) in panel (a) plus area (mnrs) in panel (b) as revenue, the net welfare gain to the U.S. is given by area (mnrs) in panel (b) minus the shaded triangles (aef + bcd) in panel (a). The net welfare loss in Canada is given by area (ghrs) in panel (b).

If Canada is able to impose an export tax on Canadian producers (voluntary quotas or increased stumpage fees), the loss to the U.S. is measured by area (abcf) in Figure 4(a). Canadian consumers gain area (P_0gsP_1) and producers lose P_0hrP_1 in Figure 4(b), but the government collects area (mnrs) in panel (b) plus area (abde) in panel (a) as revenue. The net gain to Canada is given by area (abde) in panel (a) minus the shaded areas in panel (b). Regardless of how the trade distortion comes about, the total loss in international welfare is given by the sum of the shaded areas in panels (a) and (b). Interestingly, the welfare impacts of a change in climate that affects only the boreal forests of Canada will be similar to those illustrated in Figure 3 However, their magnitude will not be the same since the starting and ending prices, which are the trade distorted prices, are different.

Finally, it is possible to examine the welfare impacts when climate changes affect both the Canadian boreal forest and forests in the United States. The foregoing model can be used to examine situations where climate changes (1) cause U.S. forest growth to be proportionally smaller than that in Canada, (2) cause greater proportional growth in the U.S. than in Canada, or (3) cause a reduction in U.S. forest productivity, but an increase in the productivity of the Canadian boreal forest.[8] In Figure 5, we illustrate only the case where there is an increase in the productivity of both the U.S. and Canadian forests.

Only two panels of the trade diagram of Figure 3 are shown in Figure 5, namely, the international market (panel (a)) and the Canadian market (panel (b)). As Canada is a surplus timber producing region, an increase in the supply of available timber due to climatic changes will shift the supply in the domestic market to the right--from S to S'. With fixed demand, this will result in an outward shift of the excess supply curve in the international market from ES to ES'. The increase in the supply of U.S. timber will result in a reduction of excess demand from ED to ED' in Figure 5(a) since the U.S. is a timber deficit region. As before, it is a simple matter to demonstrate that U.S. consumers gain more than U.S. producers could possibly lose. The net gain to Canada is given by area (abce - cdfg) in Figure 5(b), the fully shaded area minus the partially shaded area. Again it is clear that, without knowledge of the elasticities of supply and demand in the trading countries and the magnitude of the supply shifts, it is not possible to determine whether Canada is a net gainer or loser as a result of climate change.

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[8]The role of the B.C. coastal forest and other forests in other parts of the world has been ignored. However, the framework employed in the text can easily be extended to handle these cases; only the complexity of the analysis increases.

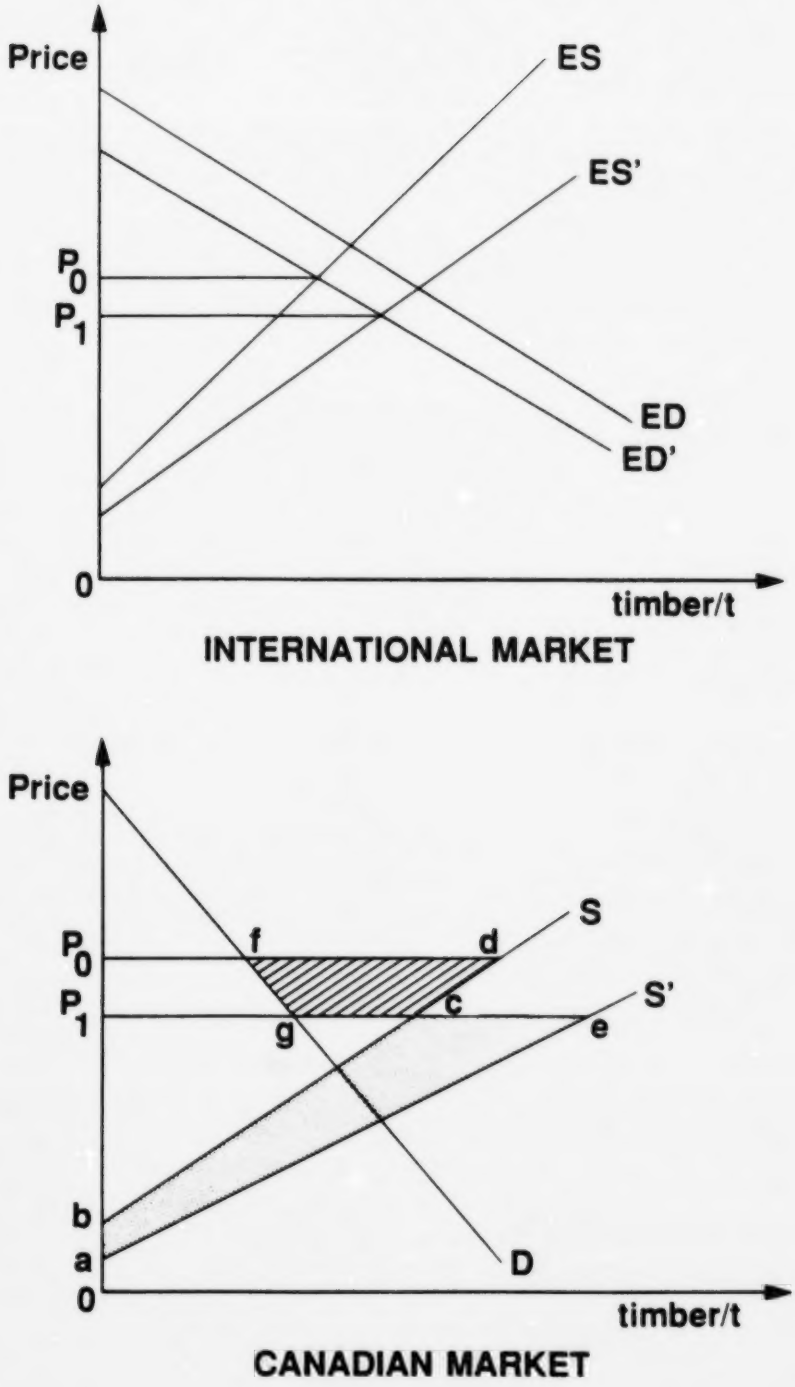


Figure 5. Welfare Gains and Losses When Climatic Change Increases the Available Timber in Both Canada and the U.S.

3.4 Systems Analysis Approach

Systems analysis is a useful approach in the case of an interdisciplinary study of the effects of a change in the environment such as the climate on another component, the forest (first order impact), which affects the forest industry, other forest related sectors and the economics of these sectors on local, national and international levels (second order impacts). It has been used in climate impact assessment (e.g. Parry et al. 1987) and in ecology (e.g. Rosswall 1971). It is especially effective for interdisciplinary studies as it provides an overview of how the different models and/or concepts fit together and relate to one another in a conceptual framework. This is provided by developing a flow diagram of the system. Iterative feedback processes and system analytical techniques such as frequency and sensitivity analysis can be used. Systems analysis can provide a research framework for creating, testing and improving mathematical and conceptual sets of interactive models.

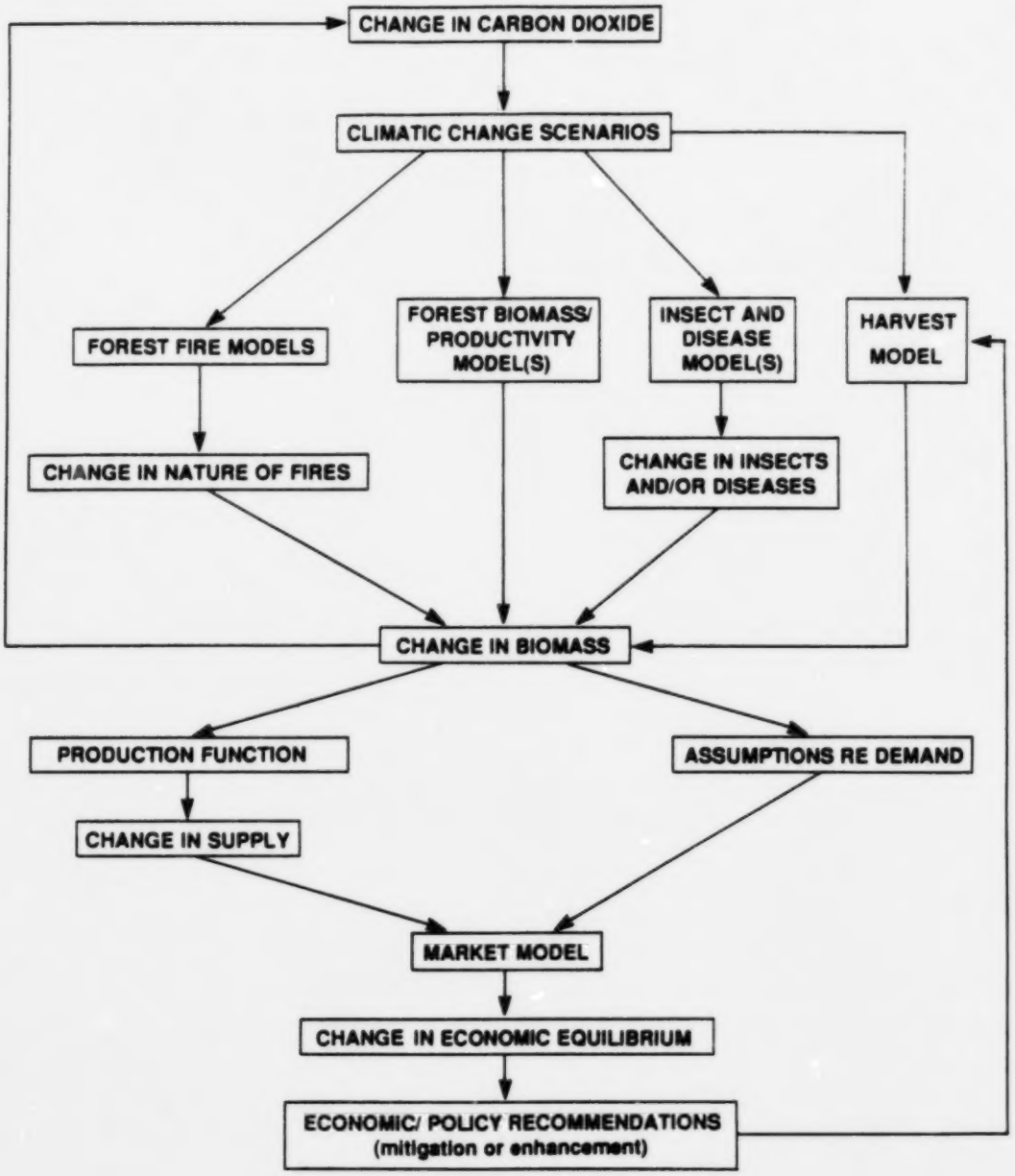
A preliminary climatic change-forest-economics system diagram is shown in Figure 6 for an example of a system approach. The main models, impacts, and feedback loops can be sketched in such a diagram. The results from each model are input to downstream models, finally leading to estimates of changes in economic welfare. A change in economic welfare would in turn be affected policy changes.

4. CONCLUSIONS AND RECOMMENDATIONS - WHERE DO WE GO FROM HERE?

When the climatological impact of rising CO_2 levels is considered, the implications for the forest and forest industry is serious and complex indeed. Yet when the direct biological impact of increasing CO_2 amounts are also examined, the matter is even further complicated. The relatively limited ranges and managed conditions under which agronomic species are grown do not apply in the case of the natural forest.

With respect to the economic implications, the foregoing analysis points out the difficulty of constructing the objective (net benefit) function to employ in an analysis of the economic benefits of climatic change on the boreal forest in Canada. It is apparent that one cannot simply employ the naive function used by Lyon and Sedjo (1983) as this does not take into account international trade, which will undoubtedly change the conclusions about the economic benefits of climatic change. Further, trade considerations enter into an analysis of secondary impacts on the economy. It is clear from Figures 3 and 5 that it is not possible to determine whether an increase in the supply of available commercial timber in Canada will lead to an overall benefit or loss to Canada, or whether there will even be an increase in timber output. Without proper specification of the objective function, therefore, it is misleading to calculate increases in economic activity by a methodology such as I-O analysis. It is important in the first instance to determine whether or not the net benefits to Canada are positive.

It is important to recognize the impacts of government policies such as countervail duties, voluntary quotas, and so on. Removal of



SYSTEM ILLUSTRATING CLIMATIC CHANGE/FOREST/ECONOMIC INTERACTIONS.

Figure 6. System Illustrating Climatic Change, Forest, Economic Interactions.

these at some future date, perhaps as a result of a Canada/U.S. free trade agreement, or imposition of additional trade restrictions, perhaps as a result of increased U.S. protectionism, would lead to welfare impacts which could be more significant than those occurring as a result of climatic changes, especially if climatic changes are rather modest.

With the details of the CO_2 warming trends as uncertain as they are in the present, particularly with respect to specific locations and small geographic areas, forest response evaluation is embryonic at best. However, as most models do show greater warming effects at higher latitudes, the potential impacts of higher atmospheric CO_2 on Canada's boreal forests should receive close and immediate attention.

Even with the uncertainty shrouding the forest response to these changed physical and chemical environments and the economic response to the changes in the forest, it is important to continue to develop methods of impact assessment. Then, hopefully, as the CO_2 climate change projections and impact modelers usage of them become more reliable, we will be able to be in an operational mode of determining, evaluating and projecting forest response.

What should our next step be? One of the means of addressing the question of the implications of climatic change for the forest and the forest industry is by the initiation of an interdisciplinary study. Such a study is now underway (Wheaton et al. 1986) as initiated by Environment Canada and it should provide the foundation for such further work.

5 ACKNOWLEDGMENTS

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